LONGLINE FISHING FOR DEEP-SWIMMING TUNAS IN THE CENTRAL PACIFIC, 1950-51

SPECIAL SCIENTIFIC REPORT: FISHERIES No. 98

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

United States Department of the Interior, Douglas McKay, Secretary
Fish and Wildlife Service, Albert M. Day, Director

LONGLINE FISHING FOR DEEP-SWIMMING TUNAS IN THE CENTRAL PACIFIC, 1950-51

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Special Scientific Report. Fisheries No. 98

WASHINGTON: MAY 1953

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INTRODUCTION

This is an interim progress report on one phase of a group of investigations by the Fish and Wildlife Service conducted through its Pacific Oceanic Fishery Investigations located in Hawaii. These investigations are designed to insure the maximum development and utilization of the high-seas fishery resources in the central Pacific. Considered herein are the first results of a longline fishing survey not yet completed. Widespread interest in these initial findings calls for their publication without delay. Owing to parallel studies in the physical, chemical, and biological oceanography of the region, it is possible to relate the results of the fishing survey to environmental causes, but no exhaustive treatment of this subject is intended here.

On the American west coast, tuna are generally taken by live-bait fishing, trolling, or purse seining. For a number of reasons apparent from extensive trials, these methods are suited neither to large-scale commercial development in the region nor to use as a survey method. The Japanese have long used the longline method commercially. This same method is proving useful in investigating the distribution and abundance of deep-swimming tunas and may have commercial possibilities in the central Pacific area.

In planning the research program, cognizance was taken of the vast area under consideration and the relatively limited resources available by confining the exploratory fishing to areas that appeared to offer a favorable environment for tunas. The general region from the Countercurrent south to the Equator seemed to be a potentially favorable environment because upwelling was known to occur there (Sverdrup et. al. 1942) and because POFI hydrographic surveys had encountered more abundant quantities of plankton at those latitudes than to the north and south. Accordingly, cruises 7 and 11 of the *Hugh M. Smith* (fig. 1) were designed to ascertain whether this potentially favorable environment was in fact more heavily populated with tunas. *Smith* Cruise 5 was primarily devoted to hydrographic studies, but it included 1 week of longlining to test the practicability of the method. Incidentally it provided some data on the abundance of deep-swimming tunas in the vicinity of Canton Island in the Phoenix group.

This report contains the results of the longline fishing for these three cruises[1] together with such related material as is available and pertinent to an understanding of the relationship of the tunas to their environment. The possibilities of commercial exploitation are also considered. Attention has been devoted to

[1] The period covered by these cruises is roughly July to November. A sequel to this report will deal with the subsequent winter and spring cruises.

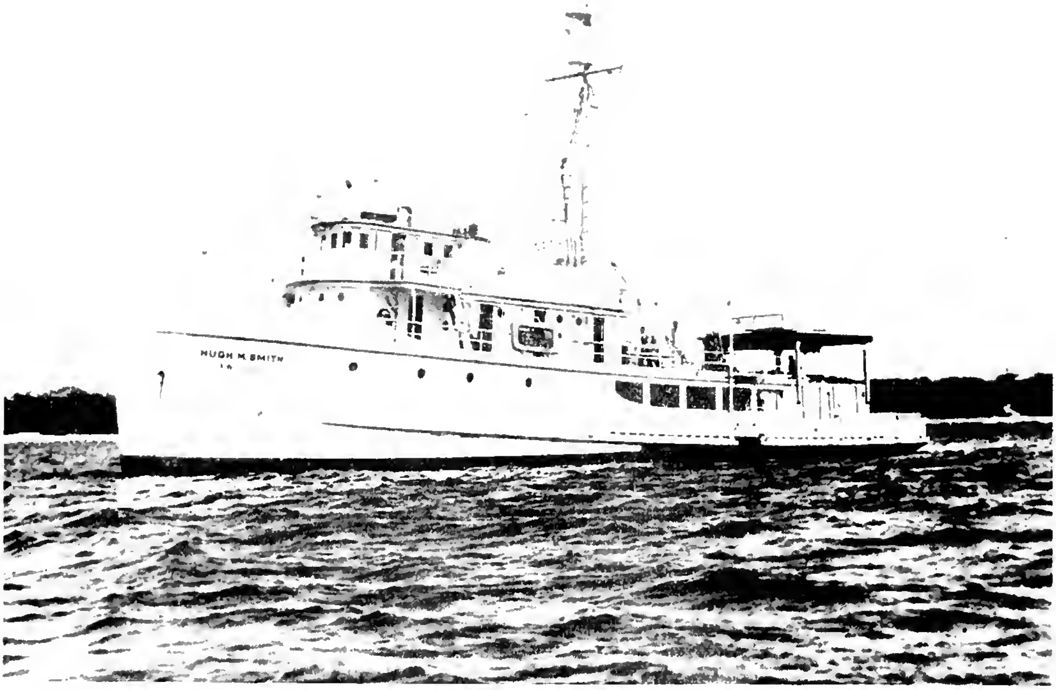

FIG. 1 THE HUGH M SMITH, A CONVERTED TUNA CLIPPER USED FOR HYDROGRAPHIC SURVEYS, LIVE BAIT FISHING, AND LONGLINE FISHING

the analysis of various mechanical and semimechanical factors that might affect the efficiency of the gear. The data relative to this problem will be presented in a separate report. With one exception there do not appear to be any factors, other than sampling variation and abundance (or availability), that seriously affect the size of the catches, and therefore the use of the catches as an index of abundance. This exception will be mentioned in an appropriate place in the text.

Throughout the body of the report the vernacular names of fishes are used. These, with their usually accepted scientific names, are as follows:

Marlin	- *Makaira* sp.
Sailfish	- *Istiophorus orientalis* (Schlegel)
Wahoo	- *Acanthocybium solandri* (Cuvier and Valenciennes)
Dolphin	- *Coryphaena hippurus* Linnaeus
Yellowfin tuna	- *Neothunnus macropterus* (Temminck and Schlegel)
Bigeye tuna	- *Parathunnus sibi* (Temminck and Schlegel)
Skipjack	- *Katsuwonus pelamis* (Linnaeus)
Albacore	- *Germo alalunga* (Bonnaterre)
Lancet fish	- *Alepisaurus* sp.
Barracuda	- *Sphyraena barracuda* (Walbaum)

ACKNOWLEDGEMENTS

Many workers were responsible for the planning and execution of the field work. Fred Cleaver was formerly responsible for the organization and planning of this experimental fishing project, and considerable credit for the knowledge gained is due to his careful planning of cruises 5 and 7. Joseph King was field party chief on *Smith* Cruise 5, Fred Cleaver on *Smith* Cruise 7, and Townsend Cromwell on *Smith* Cruise 11. O. E. Sette, M. B. Schaefer, and J. L. Kask contributed greatly to the success of the cruises through advice and direction. Finally, the successful completion of the cruises was due in large measure to the enthusiastic performance of the officers and fishermen of the *Hugh M. Smith*.

DESCRIPTION OF LONGLINE FISHING

Longline fishing catches deep-swimming tuna, and these appear to represent a different segment of the population from those found at the surface and taken by trolling and live-bait fishing. This is shown graphically in figure 2. That the size difference is not due to gear selection is indicated by data given in a later section.

Shapiro (1950) gives an excellent account of the historical development of commercial longline gear in Japan. Several authors (Shapiro 1950, June 1950, and Shimada 1951) have given complete

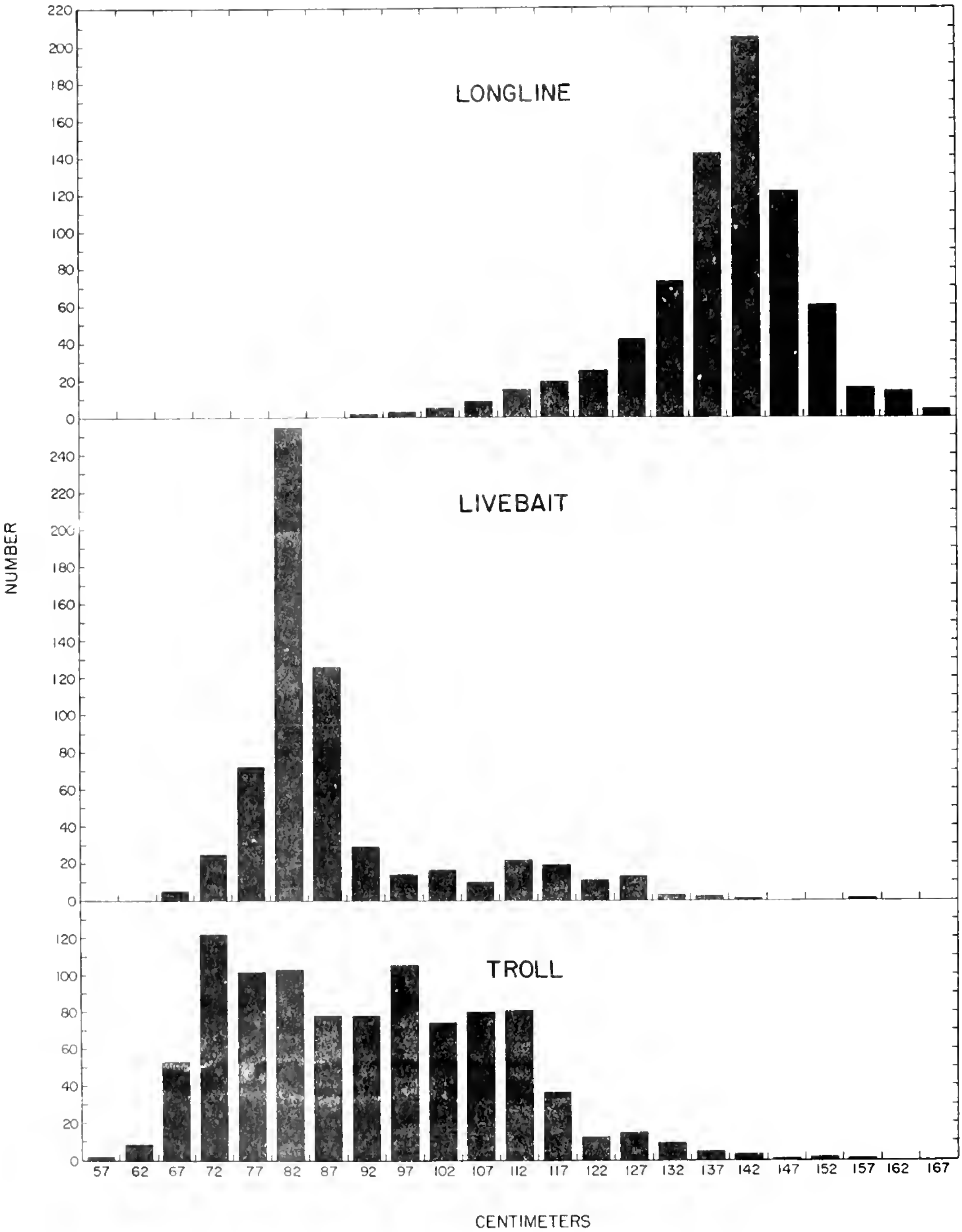

FIG. 2 SIZE OF YELLOWFIN TUNA TAKEN BY VARIOUS EXPERIMENTAL GEAR. TROLL AND LIVE-BAIT CAUGHT FISH WERE MOSTLY TAKEN NEAR ISLANDS IN THE CENTRAL PACIFIC OCEAN, e.g., LINE AND PHOENIX ISLANDS.

descriptions of various types of this gear, and Niska[2] gives a detailed account of the construction and cost of the particular gear used by POFI. For these reasons only a brief description is given in this report.

The basic unit of longline gear is the "basket." It is similar in significance to the term "skate" used in the Pacific halibut fishery. Originally it meant the amount of line that could be conveniently stored in the type of basket shown in figure 3. A "basket" consists of a length of main line to which a number of branch lines, usually five or six, are attached at intervals. Each branch line is made up of a cotton section (of the same material as the main line), a *sekiyama* (also known as "*shanawa*") section, and a wire leader to which a 9/0 or similar hook is attached.

The line currently used by POFI is designed to duplicate commercial gear in catching efficiency and at the same time furnish data suited to statistical analysis. During the course of its development the gear underwent several modifications (fig. 4), leading to the type first used on *Smith* Cruise 11. This gear has several operational advantages. It is easy to construct because of uniformity of the component parts of each basket, and this also simplifies replacement of worn out or broken parts during fishing. In addition, the amount of tangling of the branch lines is minimal because the distance between branch lines is more than twice their combined lengths.

Fishing at deep levels with the "*Smith* Cruise 11" gear is accomplished by setting the main line slack so it will sag. This sag should take the form of a catenary, and the curves in figure 5 are based on this assumption. As shown in figure 5, a wide range of theoretical or potential hook depths can be achieved by simply altering the distance between buoys when the gear is set. The actual depth attained by the hooks is, of course, also dependent on such factors as currents, which may cause the line to stream out.

The baits generally used by POFI were frozen sardines (*Sardinops caerulea*) obtained from California. The most suitable size is three or four to the pound. Before use they were thawed and packed in rock salt for about 3 days. This increased their firmness and retarded decomposition. As the line was set the baits were attached by hooking them through the eyes.

The daily fishing operation usually commenced at dawn with the setting of the gear. This operation took from 45 to 90 seconds per basket depending on the crew involved, the speed of the vessel,

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2/ Niska, Edwin. MS. Construction details of tuna longline gear used by the Pacific Oceanic Fishery Investigations.

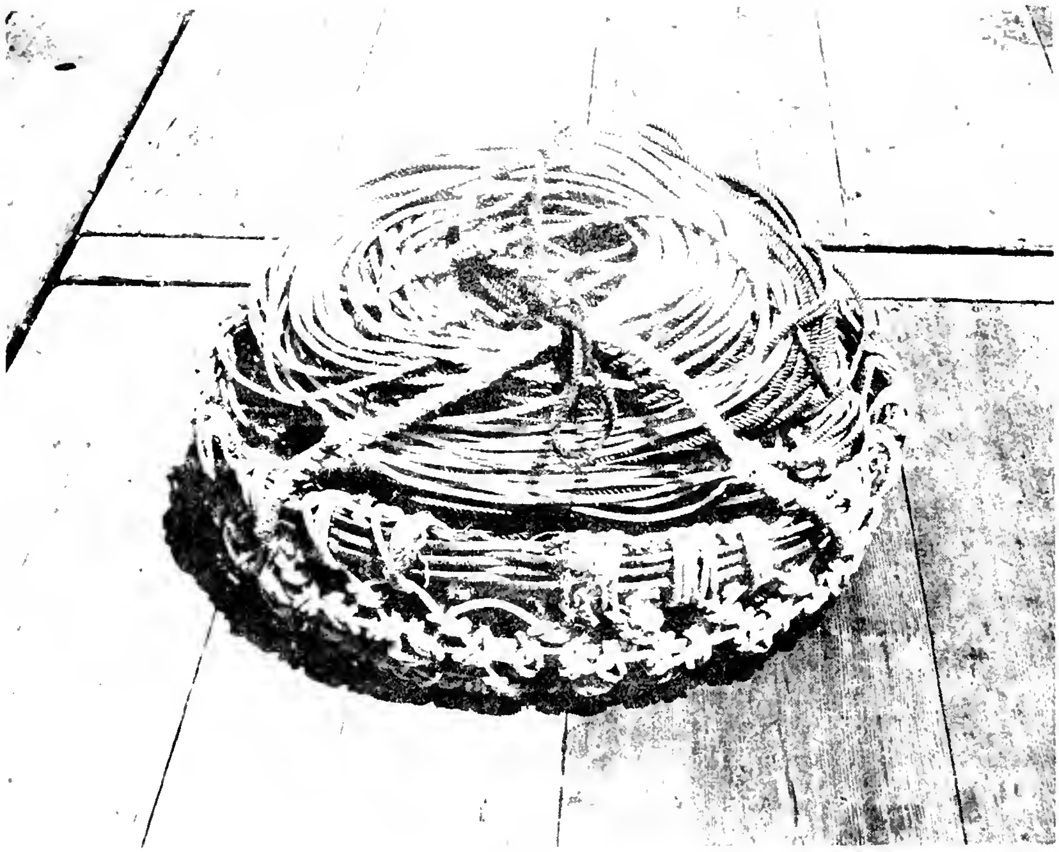


FIG. 3 A "BASKET" OF LONGLINE GEAR. EACH "BASKET" COMPRISES THE MAIN LINE SECTIONS, BRANCH LINES WITH HOOKS, AND A FLOAT LINE.

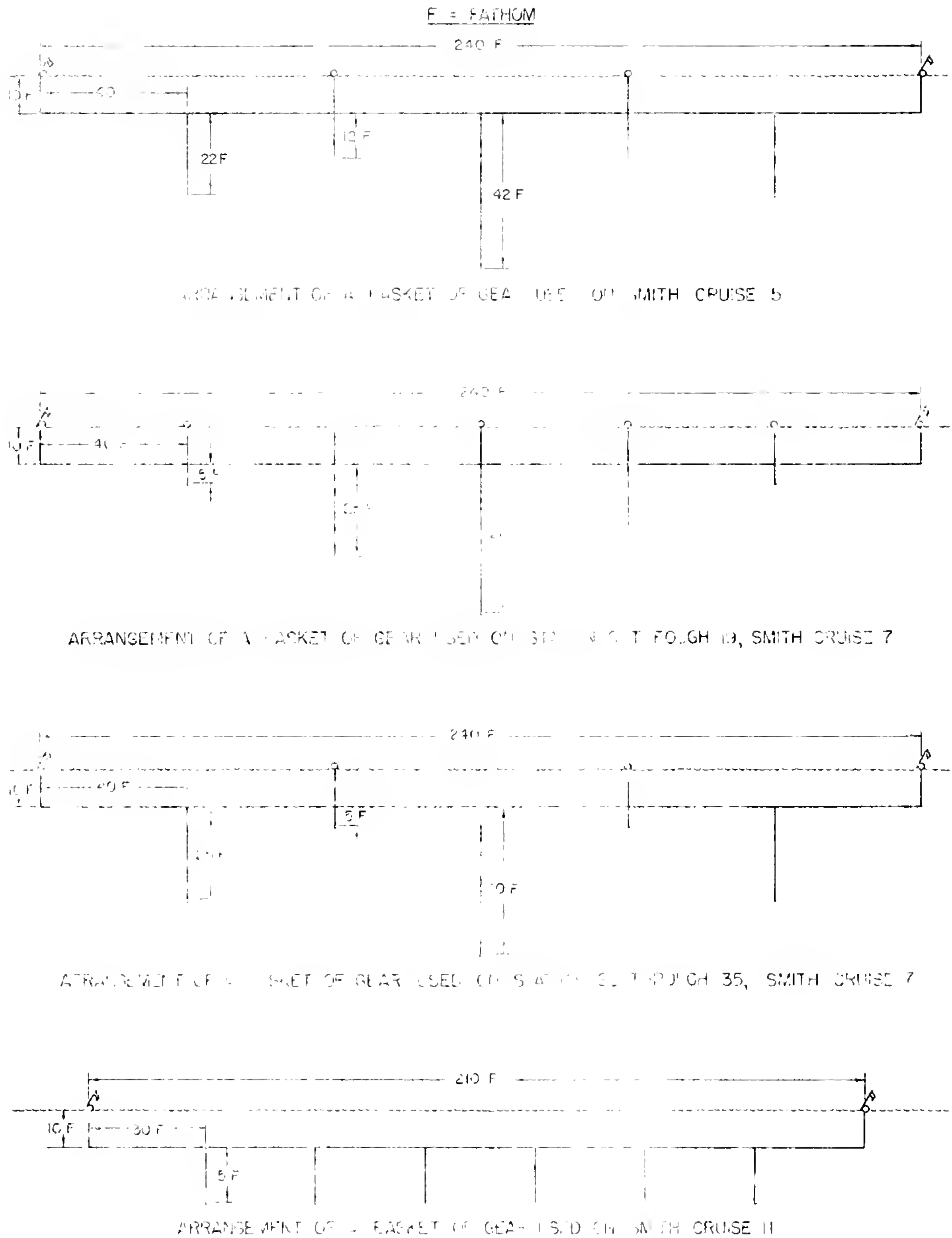


FIG 4 VARIOUS ARRANGEMENTS OF LONGLINE GEAR USED ON SMITH CRUISES 5, 7, AND 11.

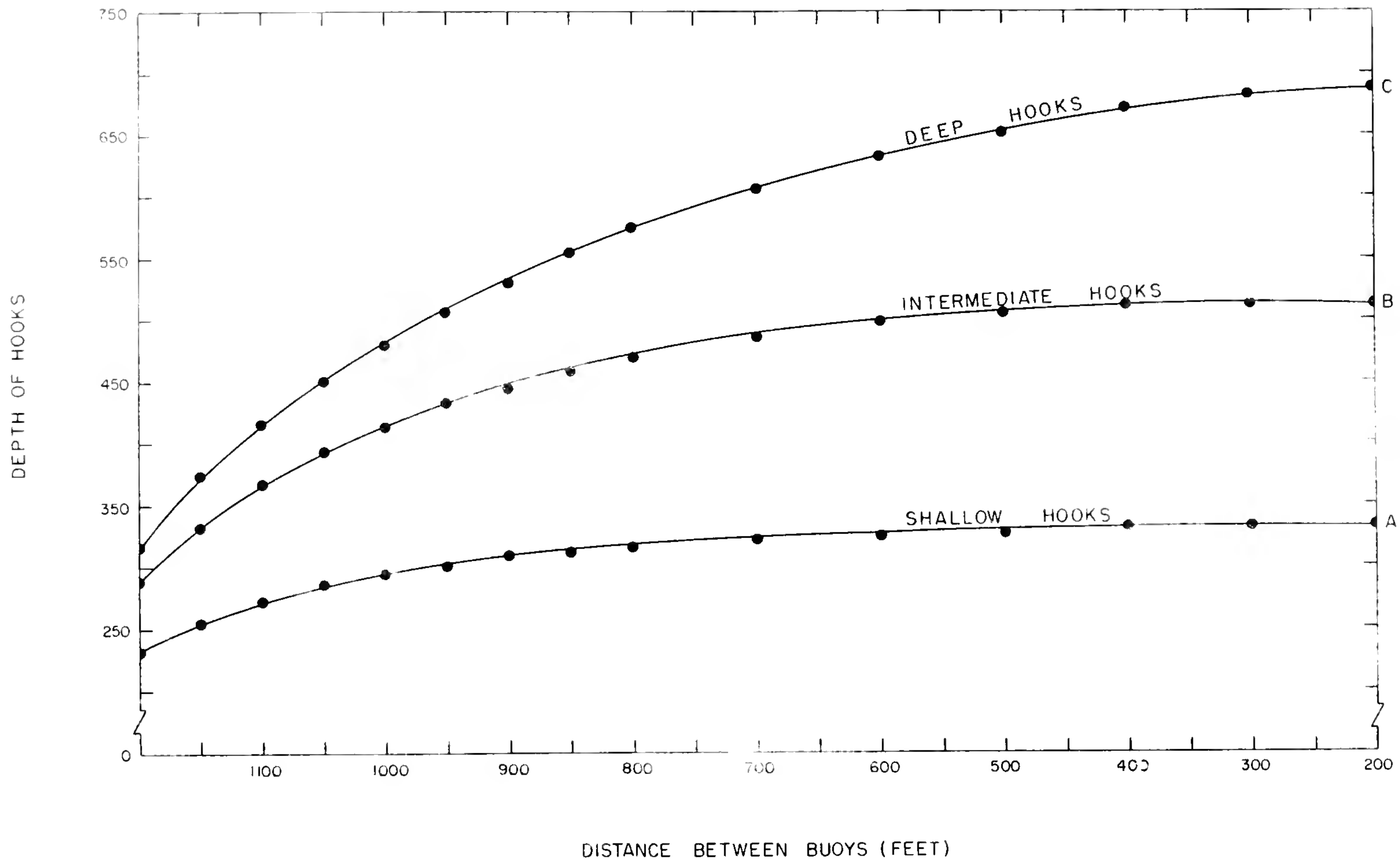


FIG. 5 "SMITH CRUISE 11" LONGLINE. THEORETICAL DEPTHS REACHED BY THE HOOKS AT VARIOUS BUOY DISTANCES. MAIN LINE LENGTH 1,260 FT.

and the distance desired between buoys. Throughout the morning the vessel kept within sight of the gear. Hauling commenced around noon and took about 4 minutes per basket of gear.

The line was set so that the vessel would be properly oriented to the wind during the retrieving process. If hauling was done from the starboard side, the line was set with the wind on the port quarter. The gear was then picked up from the end last set, which put the wind on the starboard bow. This made the vessel easier to control and prevented the wind from drifting the vessel over the line.

The actual setting of the gear can be better understood by referring to figure 6, in which the positions and duties of the crew are indicated.

The procedure for setting is as follows:

1. A 30-fathom "sea anchor" branch line is set over the starboard side.

2. A bamboo pole with the attached float and float line is cast directly over the stern;

3. A section of the main line is thrown over the starboard side;

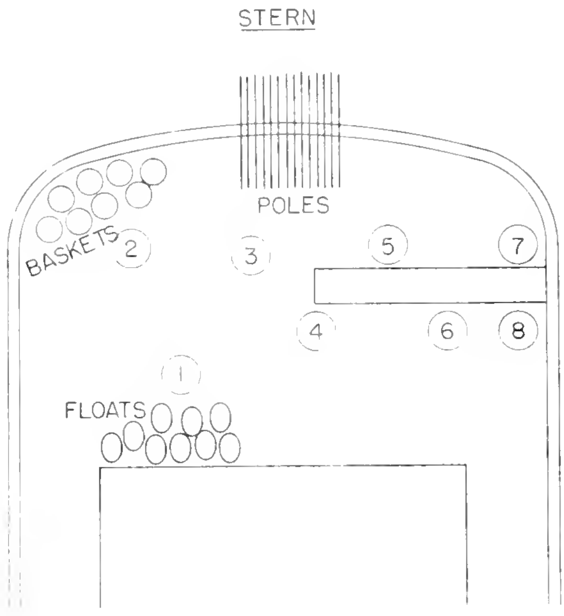
4. This is followed by a baited branch line;

5. Procedures in 3 and 4 are repeated alternately till the entire basket is set, then a float and pole assembly is attached; and

6. The entire procedure is repeated for each basket. At the end of the set another "sea anchor" branch line is set.

Hauling is done in reverse of the setting order, with the last basket set being the first to be hauled in. The retrieving of the main line was performed by a line hauler, a type of power winch imported from Japan (fig. 7). Figure 8 gives a diagram of the hauling procedure and a list of the duties of each fisherman. As each branch line reaches the roller, it is unsnapped from the main line and coiled by hand. Meanwhile, an already coiled branch line is snapped onto the loop of the main line after it has gone through the sheaves of the line hauler. A basket is completed upon the retrieving of the float line which is coiled, snapped into the main line, and placed on top of the basket. The assembled basket is then stowed away for the following day's fishing operation.

If a fish is caught on one of the branches, the line is unsnapped from the main line and the fish pulled by hand to the rail where it is gaffed and brought on board. Large fish, particularly if alive, require the attention of two or three fishermen.



NO 1 MAN PASSES FLOATS TO NO 3 MAN

NO 2 MAN PASSES BASKETS TO NO 4 MAN

NO 3 MAN SNAPS FLOATS ONTO BAMBOO POLES

NO 4 MAN PUTS BASKETS ON THE ELEVATED TABLE

NO 5 MAN JOINS FLOAT LINES TO BAMBOO POLES AND THROWS POLES WITH ATTACHED FLOATS OVERBOARD

NO 6 MAN JOINS TAIL OF ONE BASKET TO HEAD OF NEXT BASKET, THUS MAKING A CONTINUOUS MAIN LINE

NO 7 MAN THROWS OVERBOARD SECTIONS OF MAIN LINE AND FLOAT LINES

NO 8 MAN BAITS HOOKS AND THROWS BRANCH LINES OVERBOARD (BAITING IS DONE BY PASSING THE HOOK THROUGH THE EYES OF SALTED SARDINE)

FIG. 6 USUAL POSITIONS OF FISHERMEN AND EQUIPMENT DURING LONGLINE SETTING.

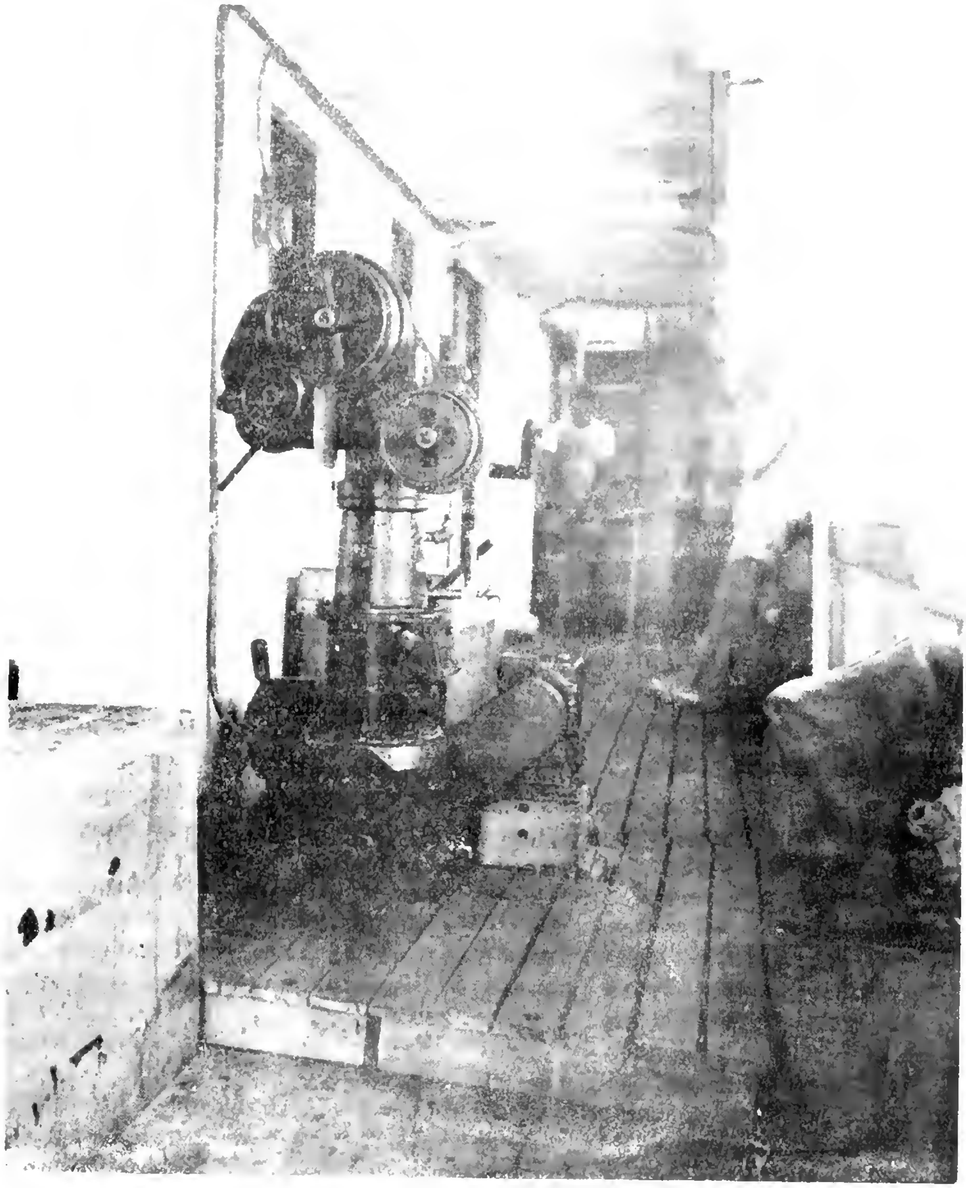
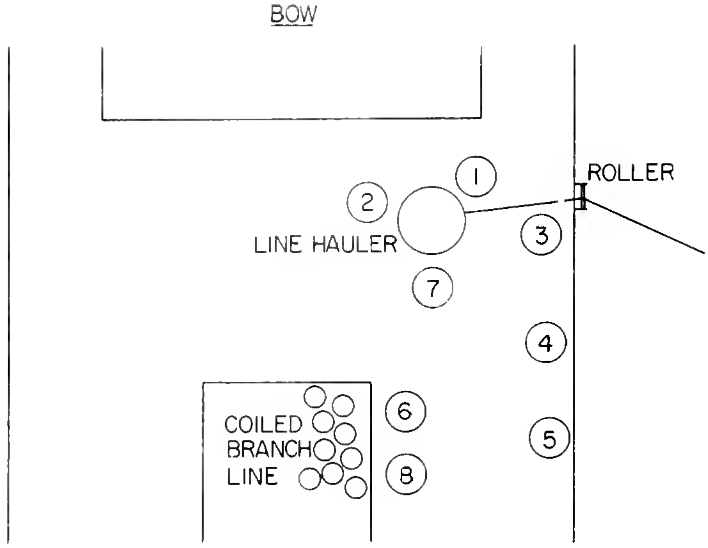


FIG. 7 LATERAL VIEW OF THE LONGLINE HAULER SHOWING THE VARIOUS SHEAVES.



NO. 1 MAN HANDLES CLUTCH OF LONGLINE HAULER AND REGULATES SPEED OF IN-COMING MAIN LINE

NO. 2 MAN WATCHES COILING OF THE MAIN LINE INTO A BASKET

NO 3 MAN UNSNAPS ALL FLOAT LINES AND BRANCH LINES FROM MAIN LINE; ALSO MOVES THE ROLLER IN THE DIRECTION FROM WHICH THE LINE IS COMING IN

NO. 4 MAN, NO 5 MAN, NO 6 MAN — COILS BRANCH LINES AND FLOAT LINES AND TAKES PART IN BRINGING ABOARD THE FISH

NO. 7 MAN SNAPS ON BRANCH LINES AND FLOAT LINES TO COMPLETE BASKET FOR FOLLOWING DAYS USE

NO 8 MAN SECURES BASKETS AND PUTS THEM AWAY FOR NEXT DAY'S OPERATION

OTHERS ASSIST IN BRINGING ABOARD FISH

FIG. 8 USUAL POSITIONS OF FISHERMEN AND EQUIPMENT DURING HAULING OPERATION.

HORIZONTAL DISTRIBUTION OF DEEP-SWIMMING TUNAS

Two of the cruises upon which this report is based were designed to ascertain the abundance of tunas in the equatorial region in the general vicinity of 150° to 160° W. longitude. The third was designed to ascertain the abundance of deep-swimming tunas in the vicinity of a small oceanic island. They are considered as a unit because they took place during a "season" when meteorological and presumably hydrographic conditions were similar, with southeast trades predominating over the Equator. The precise location of each station of the three cruises is shown in figure 9. The catches corresponding to these stations are indicated graphically in figure 10 and are listed in tables 1 to 3[3].

The distribution of the catches indicates that the pattern of variation was not a random one but rather shows a concentration of yellowfin tuna between 1° and 6° N. latitude. Generally a concentration like this arises because the fish are congregated in a particularly favorable environmental situation as far as the immediate necessities of life are concerned, or they may be congregated in a particularly favorable location for spawning.

The possibility that the abundant yellowfin tuna north of the Equator are a spawning concentration seems rather remote. Data presented by various workers (Schaefer and Marr 1948, Schaefer 1948) do not indicate well-delineated spawning areas and seasons for yellowfin tuna, without which a marked spawning concentration seems improbable, and field observations on yellowfin ovaries in the area under consideration indicate spawning is taking place during all months of the year. Spawning concentrations cannot be completely discounted, as June (1953) has shown that the period of high yellowfin catch in the Hawaiian Islands area coincides with the period of maximum spawning activity. He suggests that this fishery is based on a "spawning run."

There is, however, considerable indirect evidence that the concentration of yellowfin tuna is a response to a more favorable food supply, though direct evidence such as the demonstration that the tuna are better fed where they are more abundant is lacking. The available evidence centers around interpretation of the hydrographic features and variations in the supply of plankton in this section of the ocean.

A brief sketch of the environment during the three equatorial fishing sections is afforded by figure 11 to 13[4].

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[3] See appendix for complete catch records by station.

[4] Comparable data for stations not covered in the figures are given in the appendix. Wind direction and force for each station are also given in the appendix.

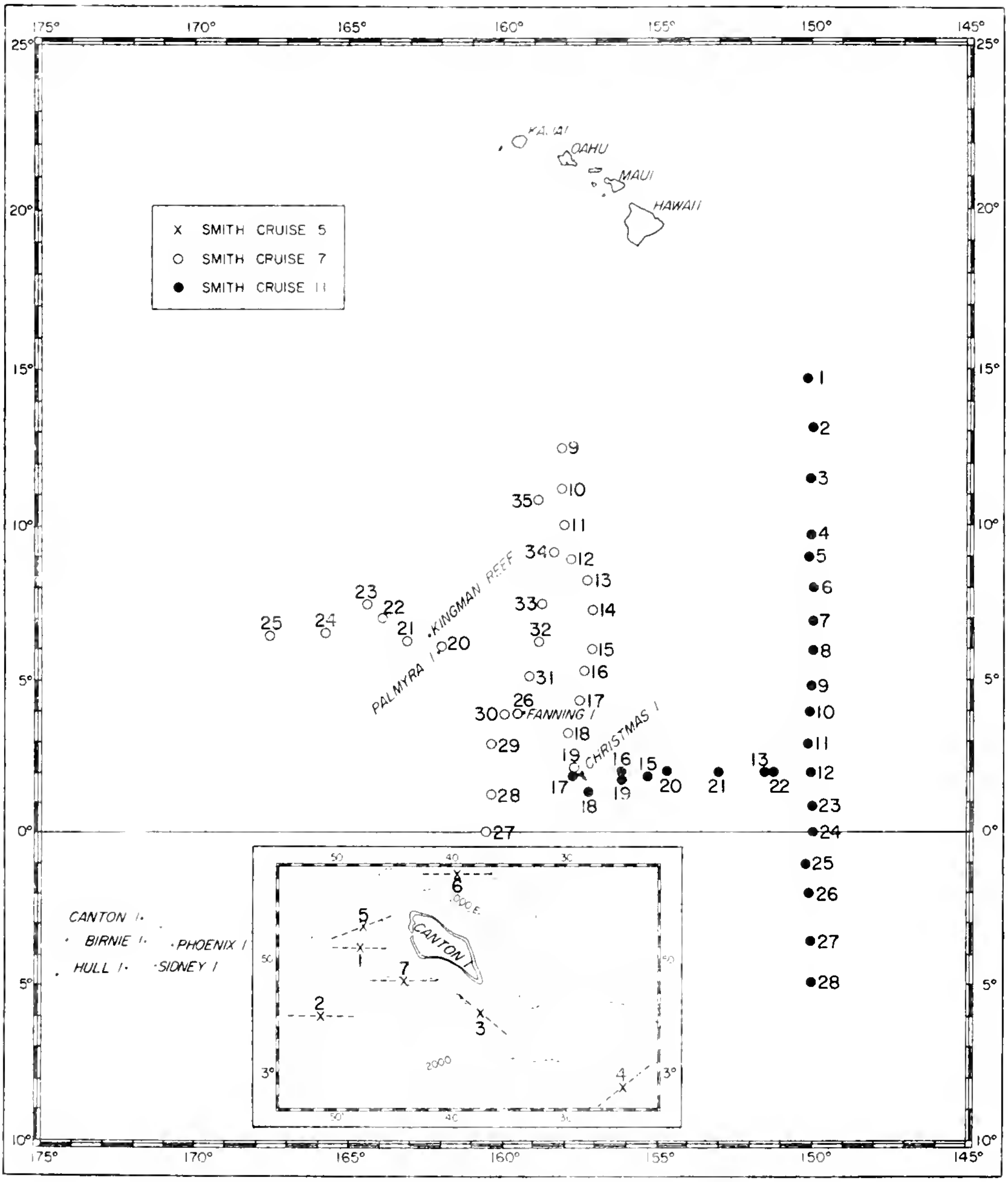

FIG 9 LOCATION OF STATIONS, SMITH CRUISES 5, 7, AND 11. (INSERT - ENLARGED STATION PLAN FOR SMITH CRUISE 5. THE DASHED LINES IN THE INSERT INDICATE THE RELATION OF THE LINE TO CANTON ISLAND.)

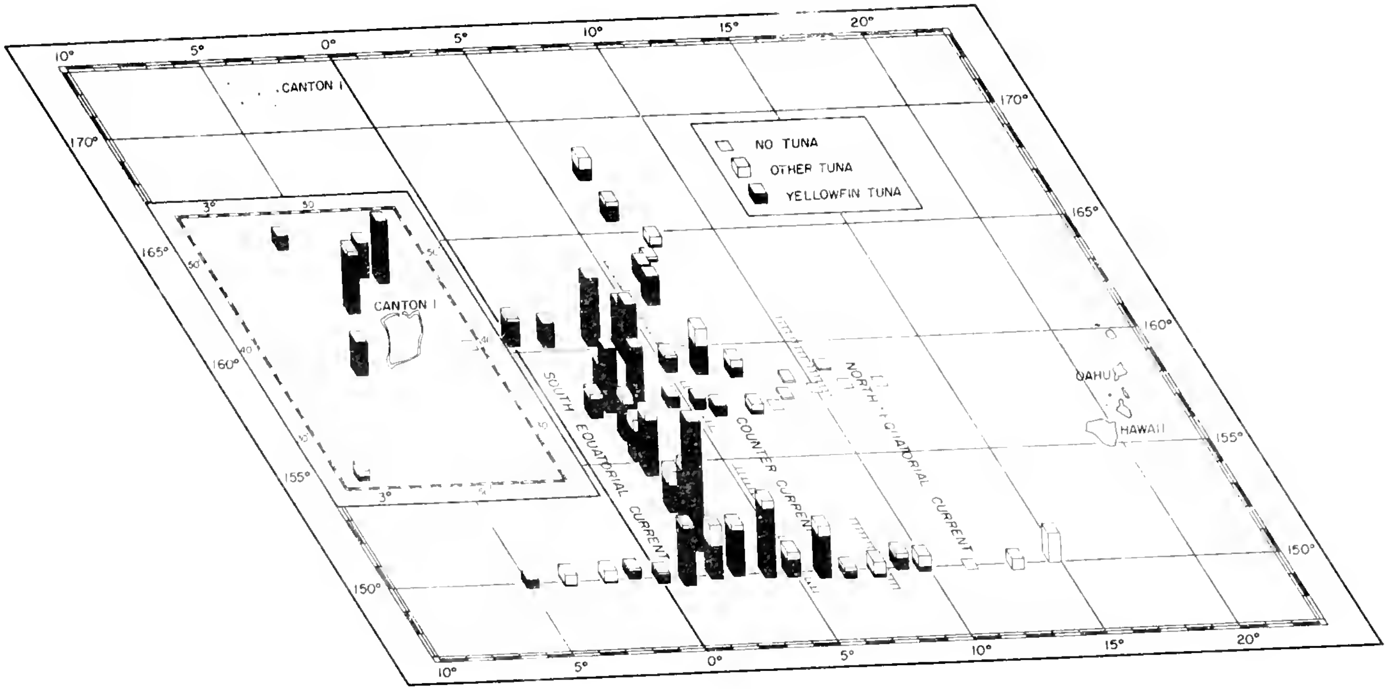

FIG. 10 CATCHES OF TUNA FOR SMITH CRUISES 5, 7, AND 11. THE BAR GRAPHS REPRESENT TUNA CATCH RATES, YELLOWFIN SHOWN IN BLACK, OTHER TUNAS IN WHITE.

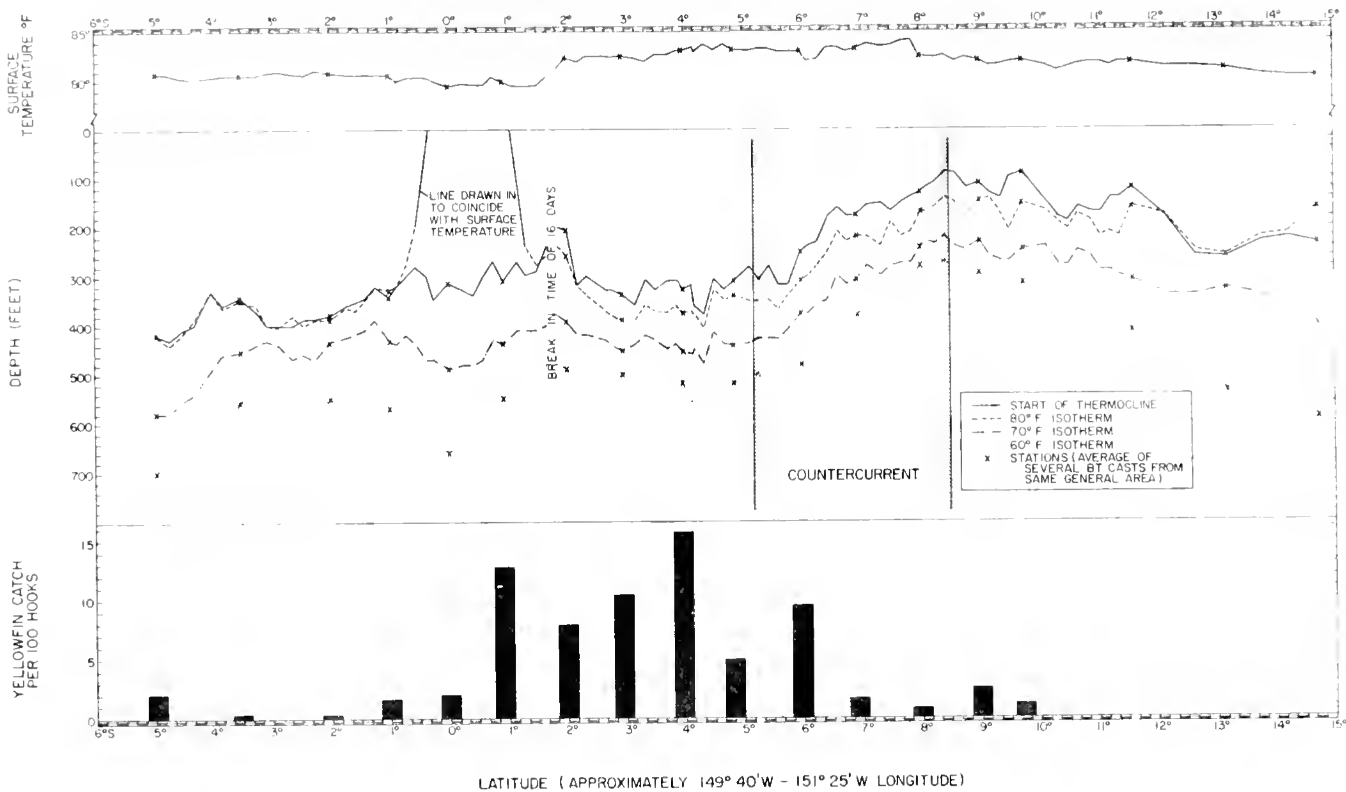

FIG. 11 VERTICAL DISTRIBUTION OF THE ISOTHERMS AT STATIONS 1 THROUGH 12 AND 23 THROUGH 28 DURING SMITH CRUISE 11. YELLOWFIN TUNA CATCHES ARE INDICATED IN THE LOWER PANEL.

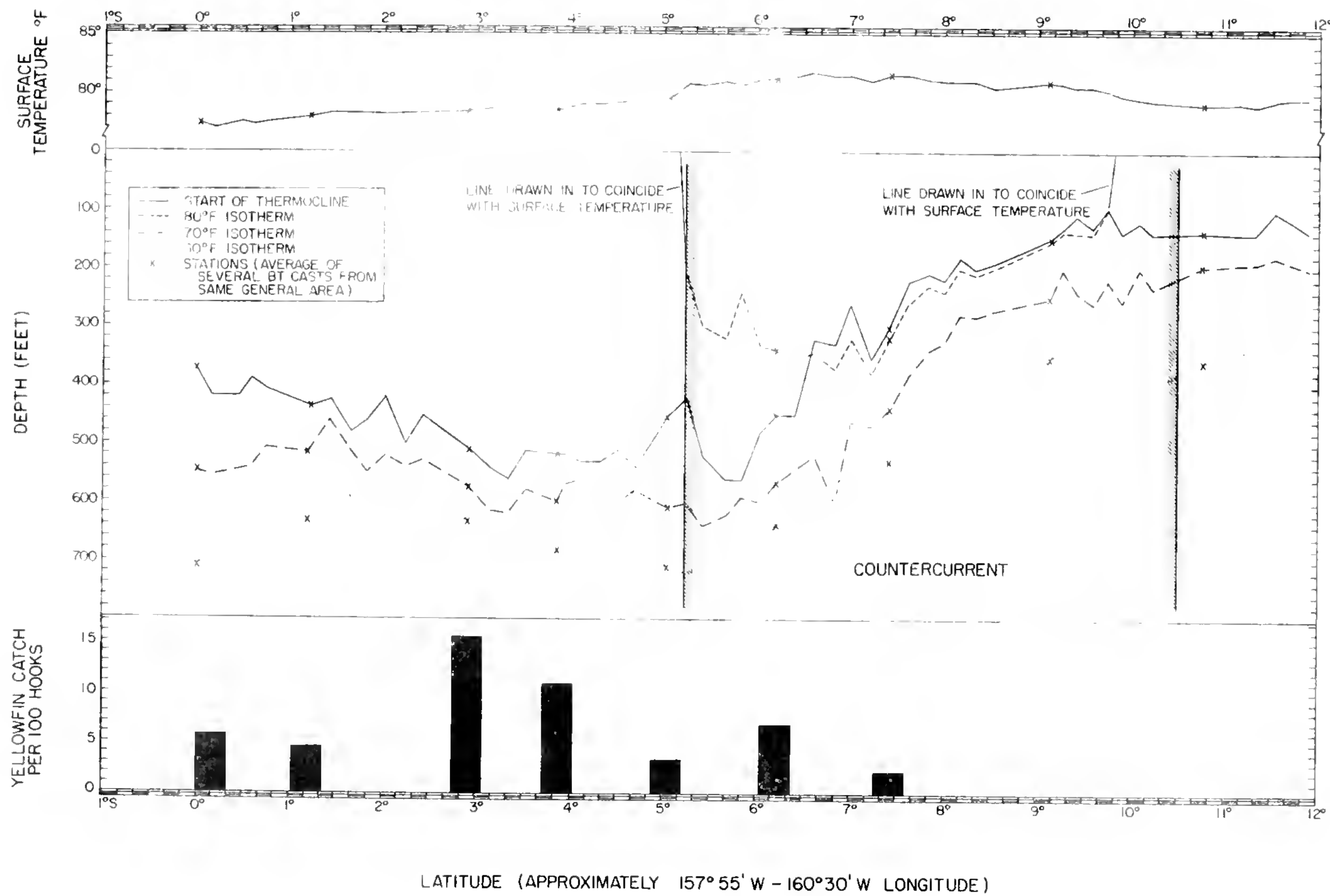

FIG. 12 VERTICAL DISTRIBUTION OF THE ISOTHERMS AT STATIONS 27 THROUGH 35 DURING <u>SMITH</u> CRUISE 7. YELLOWFIN TUNA CATCHES ARE INDICATED IN THE LOWER PANEL.

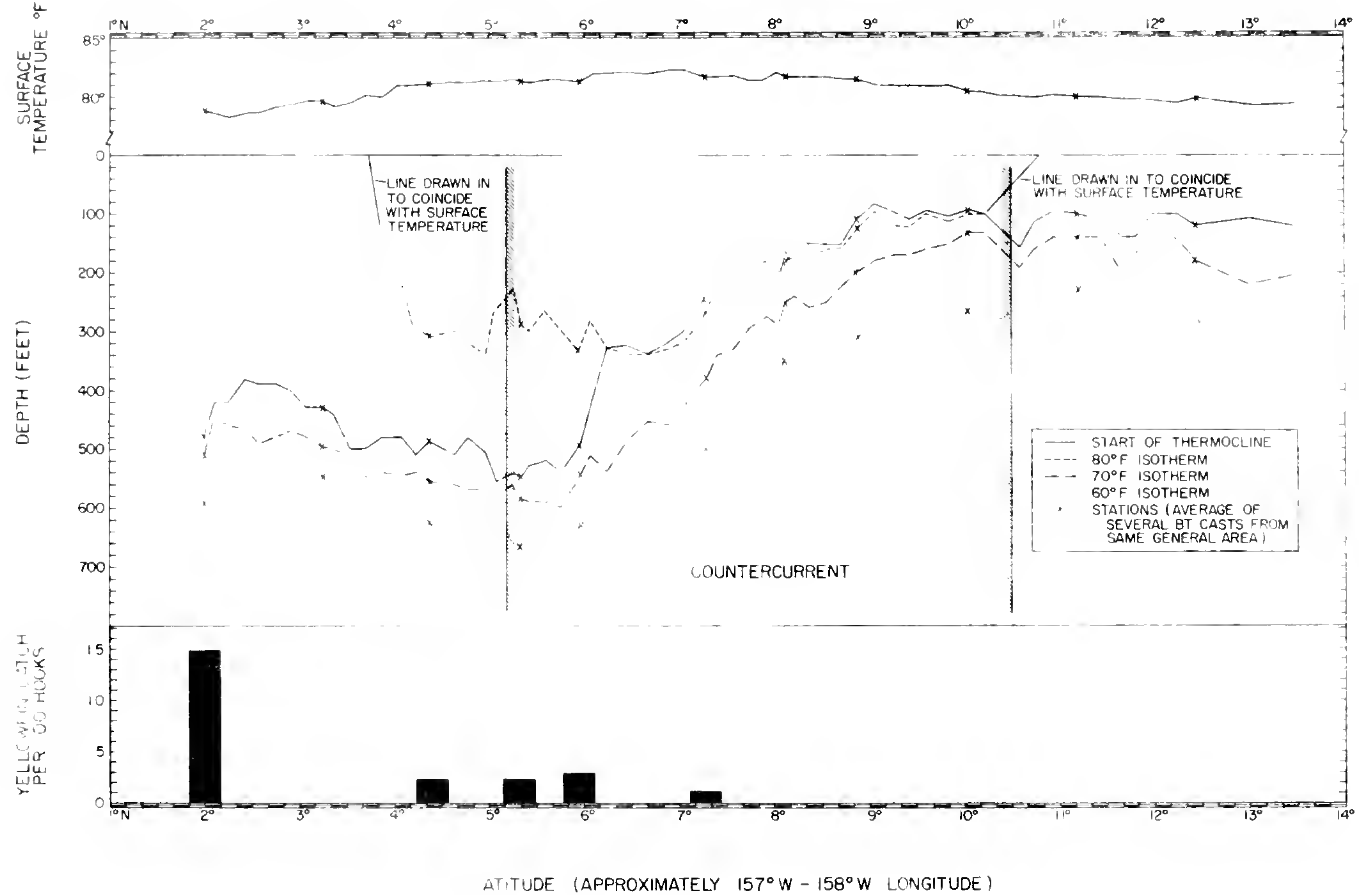

FIG 13 VERTICAL DISTRIBUTION OF THE ISOTHERMS AT STATIONS 9 THROUGH 19 DURING SMITH CRUISE 7. YELLOWFIN TUNA CATCHES ARE INDICATED IN THE LOWER PANEL.

These are longitudinal sections prepared from bathythermographs taken concurrently with the fishing stations. They indicate such recognizable features as the shallow thermocline at the northern boundary of the Countercurrent. Proceeding southward the thermocline and isotherms are found progressively deeper to a point north of the Equator. As the Equator is approached the isotherms come closer to the surface and the surface temperature decreases. This is an indication of upwelling in the vicinity of the Equator, a process that brings cooler, nutrient-rich water into the photosynthetic zone. This upwelling is wind-induced and during periods of winds from the southeast quadrant the upwelled water is displaced northward, (Cromwell 1951, Cromwell[5/]). An increased supply of zooplankton develops in this upwelled water (King and Demond 1953), and so provides greater opportunity for the maintenance of a population of animals such as tuna than is provided by the areas to the north and south not affected by the equatorial enrichment. In the upper panel of figure 14 are shown the catches at fishing stations along 150° W. longitude. The lower panel shows the plankton catches that were made at each fishing station. The general correspondence between fish and plankton is rather striking and provides an excellent indication that yellowfin tuna were abundant in the area more favorably supplied with basic foods.

Though the correspondence between the abundance of yellowfin tuna and zooplankton is striking, the two distributions diverge in several details. These do not appear serious, and since we cannot offer well-founded explanations for the divergences, they are mentioned only very briefly together with some of the possible reasons for noncorrespondence. First, the peak of tuna catch does not coincide with the peak of zooplankton abundance. Reintjes and King (1953) have shown that yellowfin tuna do not forage extensively on plankton but rather consume the small fishes, crustacea, and molluscs that feed on zooplankton. Because of this unsampled link and the probable northerly drift during the time lags in passing through the unsampled stage of the food cycle, the location of the tuna stocks should not be expected to coincide exactly with the location of the plankton. Second, the poorer catches relative to plankton abundance north of 6° N. latitude may be in part due to some of the hooks' fishing in waters too cold for yellowfin tuna. For instance, at 8° N. latitude on 150° W. longitude, where the thermocline was very shallow (fig. 11), a measurement in the field indicated that the deep hooks were fishing in water of 56° F. or colder. Third, and finally, the question may be raised as to why the bigeye tuna catches, for instance, were not greater where the yellowfin were abundant. In fact, as shown in tables 2 and 3, the bigeye appear to be more abundant north of 6° N. latitude, where few yellowfin are caught. Pending study of comparative feeding habits of the two species, no explanation is ventured. The small numbers of albacore and skipjack in the catches

5/ Cromwell, Townsend. MS. Circulation in a meridional plane in the central equatorial Pacific.

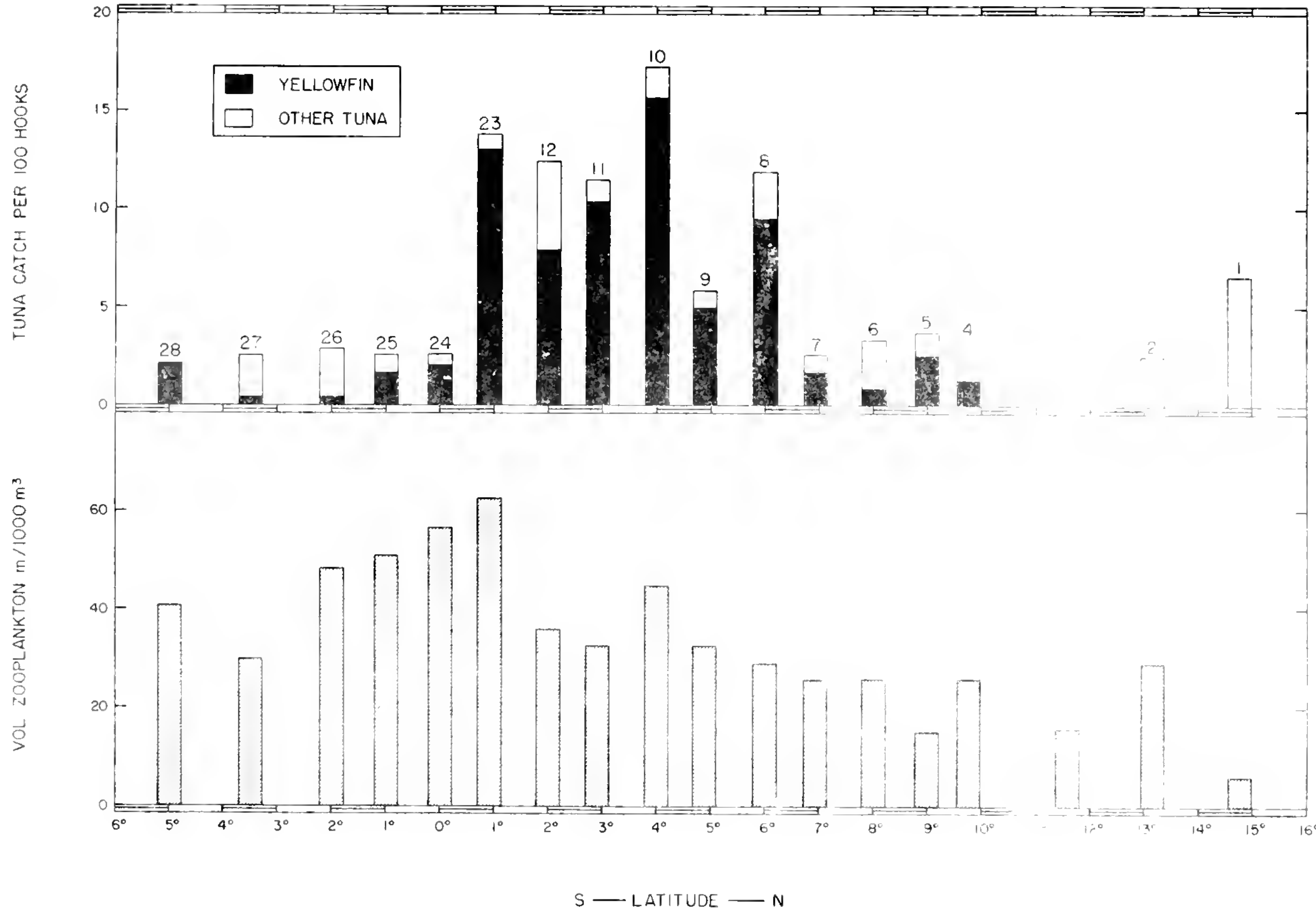

FIG. 14 AMOUNT OF ZOOPLANKTON AND CATCH OF TUNA ALONG 150° W. LONGITUDE, SMITH CRUISE 11. UNPUBLISHED PLANKTON DATA FURNISHED BY J.E. KING. THE STATION NUMBERS APPEAR AT THE TOP OF EACH BAR IN THE UPPER PANEL.

are not surprising. Both may be partially excluded from the catches by gear selection in respect to fishing depth and hook size. In addition the albacore appears to be a temperate zone species and therefore would not be expected to equal the yellowfin abundance in the equatorial zone.

Many important tuna fisheries, such as those of the Pacific coast of the Americas, are located relatively close to land. It is quite clear from figure 10 that the stocks of tuna under discussion are not related to any land masses. This is particularly evident from the lateral series extending along 2° N. latitude from Christmas Island to 150° W. longitude. On the other hand there is some evidence that the immediate vicinity of the small islands of the central Pacific presents a generally favorable habitat for tunas independent of the character of the general water masses surrounding them.

The most graphic evidence available for concentrations of tuna around the small oceanic islands is afforded by POFI trolling records. Bates (1950) records an average catch of four tuna per hour in the Line Islands area. The good fishing was limited to an area extending up to 2 miles from the reefs. Catches by POFI vessels beyond these limits are in the magnitude of one or two fish per day at best. It should be pointed out, however, that the latter are the catches resulting from trolling which is done during passage between stations, when the speed of the vessel is faster than that considered optimum for catching tuna.

There is less material available on the distribution with respect to land of the deep-swimming tunas. Three stations during Cruise 7 of the Smith (19, 20, and 26) were located very close to small islands and their catches appear to be generally higher than their oceanic counterparts. Fishing near Canton Island yielded good longline catches (table 1, fig. 11), with the stations closer to the island usually yielding the higher catches. Station 17 of Smith Cruise 11, located very close to Christmas Island, produced a catch of about the same magnitude as the oceanic stations, but the size of the yellowfin tuna was considerably smaller (fig. 15, table 11) indicating that perhaps the island catch was drawn from a different group of tuna.

In summary, the evidence points to a rather consistent relatively high abundance of yellowfin tuna in the immediate vicinity of these small oceanic islands, with the level of the oceanic stocks of deep-swimming tunas determined by factors independent of the islands. Whether the island stocks represent complete discrete populations or are merely aggregations of transient individuals is not known.

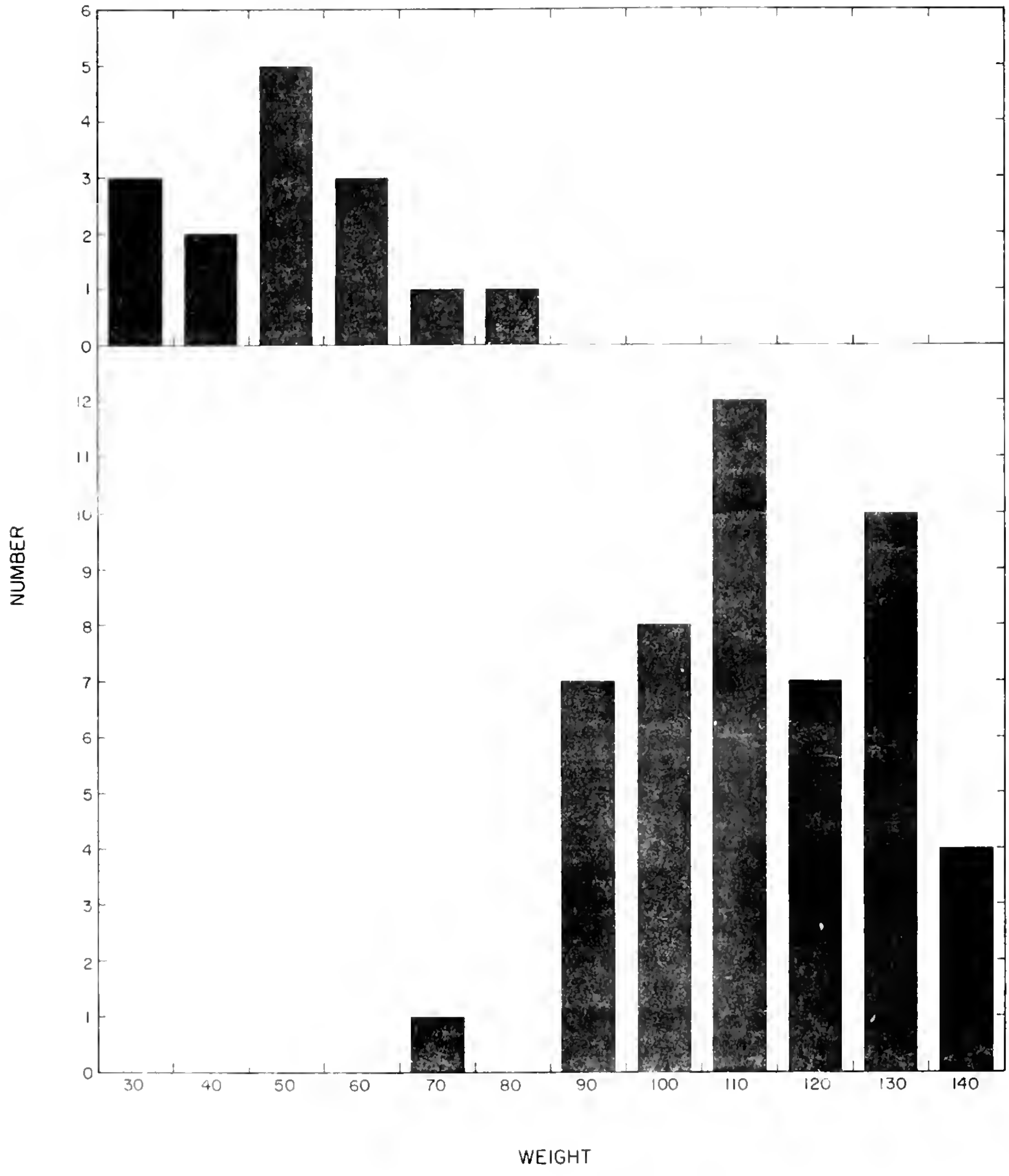

FIG. 15 UPPER PANEL – SIZE DISTRIBUTION OF YELLOWFIN TUNA TAKEN AT STATION 17. LOWER PANEL – SIZE DISTRIBUTION OF YELLOWFIN TUNA TAKEN AT STATIONS 16 AND 18, SMITH CRUISE 11. THE WEIGHTS ARE IN POUNDS AND THE NUMBER GIVEN IS THE LOWER LIMIT OF EACH CLASS.

Table 1.--Summary of the tuna catch, Smith Cruise 5, July 1950. All stations were in the vicinity of Canton Island at 3° S. latitude, 172° W. longitude. For their exact locations see figure 9.

Station	Date	Number of hooks	Catch per 100 hooks		
			Yellowfin	Albacore	Total[1]
1	7-15	127	7.1	-	7.1
2	7-16	157	3.2	-	3.2
3	7-17	152	7.9	-	7.9
4	7-18	152	1.3	1.3	2.6
5	7-19	157	14.6	-	14.6
6	7-20	152	-	-	-
7	7-21	152	13.2	1.3	14.5

[1] Calculated independently

Table 2.--Summary of the tuna catch, Smith Cruise 7, October-November 1950.

Station	Noon position		Date	Number of hooks	Catch per 100 hooks			
	Latitude	Longitude			Yellow-fin tuna	Big-eye tuna	Skip-jack	Total[1]
9	12°28'N	158°04'W	Oct. 20	125	-	-	-	-
10	11°12'N	158°04'W	Oct. 21	125	-	-	-	-
11	10°01'N	157°55'W	Oct. 22	150	-	-	-	-
12	8°52'N	157°45'W	Oct. 23	150	-	0.7	-	0.7
13	8°09.3'N	157°15'W	Oct. 24	175	-	-	-	-
14	7°17'N	157°04'W	Oct. 25	175	1.1	1.1	0.6	2.9
15	5°57'N	157°05'W	Oct. 26	175	2.9	-	-	2.9
16	5°19'N	157°20'W	Oct. 27	175	2.3	-	-	2.3
17	4°23'N	157°30'W	Oct. 28	175	2.3	-	-	2.3
18	3°17'N	157°53'W	Oct. 29	175	-	-	-	-
19	2°01'N	157°34'W	Nov. 1	175	14.9	-	-	14.9
20	6°03'N	162°00'W	Nov. 6	175	6.9	-	-	6.9
21	6°13'N	163°05'W	Nov. 7	175	4.0	-	-	4.0
22	6°59'N	163°54'W	Nov. 8	175	0.6	-	0.6	1.1
23	7°24'N	164°25'W	Nov. 9	175	0.6	1.1	0.6	2.3
24	6°31'N	165°45'W	Nov. 10	175	3.4	1.1	-	4.6[2]
25	6°25'N	167°32'W	Nov. 11	175	2.9	2.3	-	5.1
26	3°54'N	159°26'W	Nov. 16	175	13.7	-	-	13.7[3]
27	0°01'N	160°29'W	Nov. 18	175	5.7	0.6	-	6.3
28	1°12'N	160°21'W	Nov. 19	140	5.7	-	-	5.7
29	2°55'N	160°20'W	Nov. 20	175	15.4	-	-	15.4
30	3°52'N	159°57'W	Nov. 21	170	11.2	-	-	11.2
31	5°04'N	159°03'W	Nov. 23	175	3.4	0.6	-	4.0
32	6°13'N	158°53'W	Nov. 24	175	6.9	3.4	-	10.3
33	7°26'N	158°46'W	Nov. 25	175	2.3	1.1	0.6	4.0
34	9°08'N	158°19'W	Nov. 26	155	-	-	0.6	0.6
35	10°45'N	158°53'W	Nov. 27	175	-	0.6	-	0.6

1/ Calculated independently.

2/ Unidentified tuna, eaten by sharks - not included.

3/ One specimen brought up in an unidentifiable condition - jaws and eyes only - not included.

Table 3.--Summary of the tuna catch, Smith Cruise 11, August-September 1951[1].

Station	Noon position		Date	Catch per 100 hooks				
	Latitude	Longitude		Yellowfin	Bigeye	Skipjack	Albacore	Total[2]
1	14°43.5'N	150°08'W	Aug. 24	-	6.6	-	-	6.6
2	13°11'N	149°57'W	Aug. 25	-	2.5	-	-	2.5
3	11°35'N	149°59'W	Aug. 26	-	-	-	-	-
4	09°43'N	150°00'W	Aug. 27	1.2	2.1	-	-	3.3
5	08°59.5'N	150°07'W	Aug. 28	2.5	1.2	-	-	3.7
6	08°01'N	149°53'W	Aug. 29	0.8	2.5	-	-	3.3
7	06°55'N	149°54'W	Aug. 30	1.7	0.8	-	-	2.5
8	05°58'N	149°55'W	Aug. 31	9.5	2.5	-	-	12.0
9	04°50.5'N	150°01'W	Sept. 1	5.0	0.8	-	-	5.8
10	03°58.5'N	150°00'W	Sept. 2	15.7	1.7	-	-	17.4
11	02°54'N	150°07'W	Sept. 3	10.3	0.8	0.4	-	11.6
12	01°59'N	150°02'W	Sept. 4	7.9	4.1	0.4	-	12.4
13	02°01'N	151°35'W	Sept. 5	15.3	0.4	1.2	-	16.9
14[3]	02°03.5'N	153°02'W	Sept. 6	2.1	0.8	0.8	-	3.7
15	01°54'N	155°14'W	Sept. 12	7.0	1.7	0.8	-	9.5
16	02°01.5'N	156°10'W	Sept. 13	17.8	2.1	0.8	0.8	21.5
17	01°58'N	157°30'W	Sept. 14	12.4	-	-	-	12.4
18	01°22'N	157°12'W	Sept. 15	4.5	-	1.2	-	5.7
19	01°54.5'N	156°10'W	Sept. 16	8.3	1.2	0.4	-	9.9
20	02°02'N	154°40'W	Sept. 17	12.4	0.8	1.2	-	14.5
21	02°02.5'N	153°01'W	Sept. 18	6.2	3.3	-	-	9.5
22	01°59.5'N	151°16'W	Sept. 19	29.3	-	0.4	-	29.8
23	0°55.5'N	149°52'W	Sept. 20	13.0	0.4	-	0.4	13.9
24	0°00.0'	149°57'W	Sept. 21	2.1	-	-	0.4	2.5
25	01°01'S	150°13'W	Sept. 22	1.7	0.4	-	0.4	2.5
26	01°59.5'S	150°04'W	Sept. 23	0.4	1.2	0.4	0.8	2.9
27	03°32.5'S	150°02'W	Sept. 24	0.4	0.8	1.2	-	2.5
28	04°58.5'S	150°02'W	Sept. 25	2.1	-	-	-	2.1

1/ 242 hooks were fished at all stations except 23 where 238 hooks were fished.

2/ Calculated independently.

3/ Station 14 was terminated immediately after setting the line because of an emergency.

VERTICAL DISTRIBUTION

It is of considerable biological and commercial importance to know at what depths the deep-swimming tunas are most abundant. Several Japanese workers (e.g., Nakamura 1943, Uchi 1952) have noted that the catch rate of yellowfin and bigeye tuna is higher on the deeper fishing hooks though they have been unable to ascertain the precise level at which the hooks were fishing.

The construction of the POFI longline gear permits classifying the hooks according to three depth levels. The potential depths that these three levels can attain is fixed by the distance between buoys. On Smith Cruise 11 the buoys were generally between 700 and 900 feet apart. Utilizing the regression lines in figure 5, the hooks could have been fishing at approximately the following depths:

Shallow	310-320 feet
Intermediate	450-490 feet
Deep	540-610 feet

Actually the line probably streams out in response to the current gradient between the surface and the thermocline, for at one station the depth of the main line on one basket was measured at 336 feet[6]. The potential depth of this line was 550 feet. The day was calm and so the streaming effect must have been due to a differential current.

Because the exact level of the hooks is not known, the hook positions on the longlines are taken as an indication of relative depth. Tables 4 to 8 are chi-square analyses of the most pertinent data from Smith cruises 7 and 11 (Snedecor 1946, p. 188). The data were separated into five groups by species, cruises, and type of gear. Tables 4 and 5 are analyses of the yellowfin tuna catches for each of the two types of gear used on Smith Cruise 7. Table 6 is an analysis of the bigeye catches for one type of gear used on Smith Cruise 7. The catches on the other type of gear were not large enough to warrant analysis. Tables 7 and 8 are analyses of the yellowfin and bigeye catches of Smith Cruise 11. The results show very clearly that the deep hooks generally caught more bigeye and yellowfin (tables 5-8), although the shallow fishing gear used on stations 14, 15, 16, and 19 does not show this tendency (table 4, fig. 4). It is of interest to note that the mean lengths of tuna caught at the three levels of depth on Cruise 11 are almost identical (1400 mm., 1406 mm., and 1399 mm.), indicating that the three fishing levels probably were sampling the same population.

6/ The depth of the main line was measured by T. Cromwell. He attached putty balls at regular intervals to a line and hung it from a skiff using a heavy weight to keep it vertical. The skiff was then drifted over the center of the main line. The sounding line was then retrieved and the position of the shallowest dislodged putty ball noted.

Table 4.--Analysis of yellowfin tuna catch by depth[1], stations 14, 15, 16, and 19, *Smith* Cruise 7.

Station	Total number of fish	Hooks[2]			X^2
		A (1 and 5)	B (2 and 4)	C (3)	
14,15,16[3]	14	3	5	6	4.928
19	26	10	12	4	0.538
Total	40	13	17	10	5.466 Total X^2 (d.f.4) 1.124 Pooled X^2 (d.f.2) 4.342 Interaction X^2 (d.f.2)

Hypothesis: The population of yellowfin tuna is homogeneously distributed with respect to depth, therefore a 2:2:1 ratio is expected from hook groups A, B, and C.

Conclusion: The data do not differ significantly from the 2:2:1 ratio; thus the hypothesis given above is accepted.

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[1] Arrangement of gear: 5 floats per basket with 3 different lengths of droppers. See figure 4.

[2] Hook arrangements:

A: Shallow hooks (1 and 5), 5-fathom droppers.

B: Intermediate hooks (2 and 4), 25-fathom droppers.

C: Deep hook (3), a 40-fathom dropper.

[3] Stations lumped to give minimum expected numbers of 5.

Table 5.--Analysis of yellowfin tuna catch by depth[1], stations 20 through 33, Smith Cruise 7.

Station	Total number of fish	Hooks[2] A (2 and 4)	B (1 and 5)	C (3)	X^2
20, 21[3]	19	4	12	3	4.420
22-25[3]	13	1	6	6	7.961 * [4]
26	23	5	9	9	6.130 *
27, 28[3]	17	0	10	7	12.118 **
29	26	1	17	8	14.192 **
30	19	1	9	9	13.106 **
31, 32, 33[3]	20	1	13	6	10.250 **
Total	137	13	76	48	68.177 ** Total X^2 (d.f. 14) 55.573 ** Pooled X^2 (d.f. 2) 12.604 Interaction X^2 (d.f. 12)

Hypothesis: The population of yellowfin tuna is homogeneously distributed with respect to depth, therefore a 2:2:1 ratio is expected from hook groups A, B, and C.

Conclusion: The significant X^2 value of 68.177 ($P \leqslant 0.01$) indicates that the data differ significantly from the expected 2:2:1 ratio, thus the hypothesis given above is rejected.

[1] Arrangement of gear: 3 floats per basket with 3 different lengths of droppers. See figure 4.

[2] Hook arrangements:
A: Shallow hooks (2 and 4), 5-fathom droppers.
B: Intermediate hooks (1 and 5), 25-fathom droppers.
C: Deep hook (3), a 40-fathom dropper.

[3] Stations lumped to give minimum expected numbers of 5.

[4] The notations * and ** indicate that the statistic is significant at the 0.05 level and 0.01 level respectively.

Table 6.--Analysis of bigeye tuna catch by depth[1/], *Smith* Cruise 7.

Station	Total number of fish	Hooks[2/]			X^2
		A (2 and 4)	B (1 and 5)	C (3)	
20 thru 35[3/]	18	1	8	9	13.528** Pooled X^2 (d.f.2)

Hypothesis: The population of bigeye tuna is homogeneously distributed with respect to depth, therefore a 2:2:1 ratio is expected from hook groups A, B, and C.

Conclusion: The significant pooled X^2 value of 13.528 ($P<0.01$) indicates that there is a difference in catch from the 2:2:1 ratio. Before conclusions can be drawn it should be noted that due to the insufficient amount of data available, the values have been pooled and no analysis of interaction made.

1/ Arrangement of gear: 3 floats per basket with 3 different lengths of droppers. See figure 4.

2/ Hook arrangements:

A: Shallow hooks (2 and 4), 5-fathom droppers.

B: Intermediate hooks (1 and 5), 25-fathom droppers.

C: Deep hook (3), a 40-fathom dropper.

3/ Stations lumped to give minimum expected numbers of 5.

Table 7.-- Analysis of yellowfin catches by depth, Smith Cruise 11.

Station	Total number of fish	A (hooks 1 and 6)	B (hooks 2 and 5)	C (hooks 3 and 4)	X^2
4, 5, 6, 7 1/	15	5	8	2	3.600
8	23	3	9	11	4.522
9, 10 1/	50	10	16	24	5.920
11	25	6	5	14	5.840
12	19	7	6	6	0.106
13	37	9	15	13	1.514
14, 15 1/	22	4	10	8	2.546
16	42	11	13	18	1.857
17	30	9	8	13	1.400
18, 19 1/	31	8	15	8	3.162
20	29	5	9	15	5.241
21	15	5	6	4	0.400
22	71	23	25	23	0.113
23	30	9	11	10	0.200
24-28 1/	16	1	9	6	6.125*
Total	455	115	165	175	42.546 Total X^2 (d.f. 30) 13.627** Pooled X^2 (d.f. 2) 28.919 Interaction X^2 (d.f. 28)

Hypothesis: The population of yellowfin tuna is homogeneously distributed with respect to depth, therefore 1:1:1 ratio is expected from hook groups A, B, and C.

Conclusion: There is no significant interaction between the data, i.e., the values in the cells do not vary significantly from the border totals. Therefore the pooled figure for the cruise can be used. The data differ significantly from the 1:1:1 ratio, and the above hypothesis is rejected.

1/ Stations lumped to give minimum expected numbers of 5.

Table 8.--Analysis of bigeye tuna catch by depth, Smith Cruise 11.

Station	Total number of fish	A (hooks 1 and 6)	B (hooks 2 and 5)	C (hooks 3 and 4)	X^2
1	16	5	2	9	4.625
2,4,5,6[1]	20	5	5	10	2.500
7,8,9,10,11[1]	15	-	7	8	7.600 *
12,13,14,15[1]	17	2	9	6	4.353
16 - 28[1]	25	1	8	16	13.520 **
Total	93	13	31	49	32.598 ** Total X^2 (d.f.10) 20.904 ** Pooled X^2 (d.f.2) 11.694 Interaction (d.f.8)

Hypothesis: The population of bigeye tuna is homogeneously distributed with respect to depth, therefore a 1:1:1 ratio is expected from hook groups A, B, and C.

Conclusion: There is no significant interaction between the data, i.e., the values in the cells do not vary significantly from the border total. Therefore the pooled figure for the cruise can be used. The data differ significantly from the 1:1:1 ratio, and the above hypothesis is rejected.

1/ Stations lumped to give minimum expected numbers of 5.

SIZE COMPOSITION AND SEX RATIOS OF THE TUNA

The size composition of the longline catch of deep-swimming tunas is of considerable interest both to the biologist and the commercial fisherman. Weight frequencies for the important species are given in tables 9 - 11 (also see fig. 2). They indicate very clearly that either the longline gear selectively catches large fish or the deep-swimming population is made up chiefly of large fish.

It is difficult to point out physical reasons why tunas as small as 20 pounds cannot be readily hooked on the gear. The capture of 21 skipjack of from 10 to 29 pounds (table 11) supports this view, but significantly this size is entirely absent from the yellowfin tuna catches. Small albacore and some small bigeye are also taken occasionally. The smaller size of the fish caught off Christmas Island (fig. 15, station 17) is a further indication that when small fish are in the population they are taken by the longline. It might be argued that small yellowfin tuna are present at the deeper levels but are not taken because of selective feeding. Reintjes and King (1953), however, found that yellowfin tuna over the entire size range covered by trolling, live-bait fishing, and longline fishing (fig. 2) have about the same feeding habits. Tentatively it can be concluded the longline samples only the larger individuals of yellowfin and bigeye populations because these larger sizes are dominant at the deep levels at which the gear fishes.

The sex ratios of the yellowfin and bigeye tuna taken on the three cruises are given in table 12. There was a preponderance of males in each instance, the ratio of males to females varying from 1.5 to 1 to 2.7 to 1. The dominance of males may add weight to the argument that the longline is sampling a limited portion of the population, for it is difficult to ascribe this difference to gear selection, or it may indicate such phenomena as differential growth or mortality.

Table 9.--Weight frequency of tunas taken on <u>Smith</u> cruises 5 and 7.

Pounds	Cruise 5		Cruise 7		
	Yellowfin tuna	Albacore	Yellowfin tuna	Bigeye tuna	Skipjack
0 - 9	-	-	-	-	-
10 - 19	-	-	-	-	2
20 - 29	-	1	-	-	2
30 - 39	-	3	-	1	-
40 - 49	1	-	2	-	-
50 - 59	4	-	1	-	-
60 - 69	12	-	2	-	-
70 - 79	6	-	10	1	-
80 - 89	5	-	5	-	-
90 - 99	3	-	12	1	-
100 - 109	8	-	22	-	-
110 - 119	5	-	23	3	-
120 - 129	4	-	32	-	-
130 - 139	1	-	18	-	-
140 - 149	-	-	4	2	-
150 - 159	1	-	3	2	-
160 - 169	1	-	1	2	-
170 - 179	-	-	1	1	-
180 - 189	1	-	-	1	-
190 - 199	-	-	1	-	-
200 - 209	-	-	-	-	-
210 - 219	-	-	-	-	-
220 - 229	-	-	-	-	-
230 - 239	-	-	-	1	-
240 - 249	-	-	-	-	-
250 - 259	-	-	-	-	-
260 - 269	-	-	-	-	-
270 - 279	-	-	-	-	-
280 - 289	-	-	-	-	-
290 - 299	-	-	-	-	-
300 - 309	-	-	-	-	-
310 - 319	-	-	-	-	-
320 - 329	-	-	-	1	-

Table 10. -Yellowfin tuna weight frequencies fo Smith Cruise 11.

Weight in pounds	Station																							
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	28	Total
30- 39	-	-	-	-	1	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	4
40- 49	-	-	1	-	1	-	-	-	-	-	-	-	-	2	-	-	1	-	-	-	-	-	-	-	5
50- 59	-	-	-	-	5	1	1	1	-	-	-	-	-	5	-	-	-	-	-	-	-	1	-	-	14
60- 69	-	1	-	-	1	1	1	1	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	1	9
70- 79	-	-	-	-	-	-	1	-	-	1	1	-	-	1	1	-	-	-	-	-	-	-	1	1	7
80- 89	1	1	1	1	-	-	2	3	2	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	13
90- 99	-	1	-	-	-		3	3	2	6	2	2	6	-	1	-	6	3	2	-	-	-	-	2	39
100-109	-	1	-	-	-	1	8	6	3	8	1	2	7	-	1	4	4	1	5	4	2	-	-	-	53
110-119	-	1	-	1	2	2	11	5	2	11	-	6	10	-	2	5	[illegible]	2	18	4	1	1	-	-	91
120-129	-	-	-	-	2	2	2	2	5	4	1	2	6	-	1	3	3	2	13	5	-	1	-	1	55
130-139	1	-	-	1	1	1	1	1	2	5	-	1	8	-	2	3	-	4	11	7	-	-	-	-	53
140-149	-	-	-	-	-	1	2	1	1	2	-	-	2	-	2	-	-	1	6	3	-	-	-	-	21
150-159	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	4	2	-	-	-	-	8
160-169	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-	1	1	3	-	-	-	-	7
170-179	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1
180-189	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
190-199	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1

Table 11.--Weight frequency of tunas other than yellowfin tuna, Smith Cruise 11.

Pounds	Bigeye	Albacore	Skipjack
10 - 19	1	1	4
20 - 29	-	-	17
30 - 39	1	1	-
40 - 49	2	3	-
50 - 59	1	2	-
60 - 69	1	-	-
70 - 79	1	-	-
80 - 89	3	-	-
90 - 99	2	-	-
100 - 109	2	-	-
110 - 119	3	-	-
120 - 129	5	-	-
130 - 139	6	-	-
140 - 149	3	-	-
150 - 159	5	-	-
160 - 169	4	-	-
170 - 179	3	-	-
180 - 189	5	-	-
190 - 199	7	-	-
200 - 209	6	-	-
210 - 219	3	-	-
220 - 229	5	-	-
230 - 239	5	-	-
240 - 249	4	-	-
250 - 259	3	-	-
260 - 269	3	-	-
270 - 279	1	-	-
280 - 289	1	-	-
290 - 299	-	-	-
300 - 309	-	-	-
310 - 319	-	-	-
320 - 329	-	-	-
330 - 339	1	-	-

Table 12.--Sex ratios of tunas taken on Smith cruises 5, 7, and 11.

	Male	Female	Ratio Males:Females
Cruise 5			
Yellowfin tuna	27	10	2.7 : 1
Cruise 7			
Yellowfin tuna	41	22	1.9 : 1
Bigeye tuna	22	10	2.2 : 1
Cruise 11			
Yellowfin tuna	232	151	1.5 : 1
Bigeye tuna	53	35	1.5 : 1

COMMERCIAL POSSIBILITIES

The only large-scale commercial longline fishing for tuna is conducted by the Japanese. In 1950 and 1951 the Japanese fishing industry sent nine tuna mothership longline fishing expeditions into the equatorial area west of 180°. Details of these can be found in papers by Shimada (1951), Ego and Otsu (1952), and Van Campen (1952). That these expeditions met with success is implied by their number. This, however, does not mean that a similar venture in the same area, if undertaken by American fishermen, would be financially successful, because there are differences in basic costs. For instance, a Japanese fisherman's income is equivalent to $50-75 for a fishing trip lasting a month (Ego and Otsu 1952).

The survey fishing reported herein has revealed a greater concentration of tuna in the equatorial waters of the central Pacific area than has been found in the far western Pacific by the Japanese. This is indicated by a catch rate of 12.3 yellowfin tuna per hundred hooks in the rich area just north of the Equator between 150° and 157° W. longitude[7] as compared to an average of approximately three tuna of all species per hundred hooks for the nine Japanese expeditions (Ego and Otsu 1952) in the western Pacific. As yet, definite conclusions in relation to an American fishery cannot be drawn, since the 12.3 yellowfin per hundred hooks is based on one cruise (Smith Cruise 11) covering 2 months, August and September 1951, although some corroboration is found in the results of Smith Cruise 7. By contrast the Japanese expeditions cover a number of months through 2 years.

A detailed study of the catch rates, fishing time, seasonal variation, and other factors concerning availability of tuna in the central Pacific must be completed before definitive comparisons between the two areas can be made. However, there is little doubt that commercial fishing by an American vessel would be feasible if catches were as high as those experienced by the Smith on Cruise 11. By way of comparison, the first six Japanese expeditions averaged about three tuna totaling 250 pounds per hundred hooks. Our survey fishing in the rich latitudes in the vicinity of 150° W. longitude brought in 12.3 yellowfin per hundred hooks, equivalent to 1,500 pounds. If a purse seine-type vessel with a crew of 12 men were able to fish 900 hooks per day, and if it maintained an average rate of capture of 12.3 yellowfin, 13,500 pounds of yellowfin per day could be expected. This probably is enough to support an American fishing boat, even when considering deductions for shark damage and cannery rejection.

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[7] This figure is based on stations 10-23 of Smith Cruise 11, excepting station 14. The selection was not entirely arbitrary as the poor catch stations to the north and south were fished only in order to delimit the rich zone.

Sharks have ample opportunity to damage the catch because tuna caught by longline remain in the water for varying periods before they are brought aboard. During this period they are susceptible to attack by the sharks in the deep waters. However, the greatest damage appears to be done during hauling, when sharks inhabiting the surface layers attack the fish. These sharks have been found in varying abundance throughout the equatorial waters, usually with larger numbers occurring close to land. The amount of shark-damaged tuna for all three cruises is disturbing (table 13), but it is probable that it can be considerably reduced by rapid mechanical hauling of the hooked fish. In addition, a number of the fish classed as shark-bitten in table 13 could have been salvaged for canning.

Acceptability of the catch for canning is another vital problem in evaluating the possibilities for a longline fishery. The catches of Smith cruises 7 and 11 were sold to canneries in the Territory of Hawaii. Rejection by the cannery of the catch from Smith Cruise 7 amounted to about one-third by weight of all species. Records are not available for examining the distribution of the rejections by sizes or species for this cruise. The acceptability was based entirely on color of the cooked flesh. The color becomes apparent only after precooking and partially dismembering the fish, at which time weights and species identification become uncertain. For the next landing, that of Smith Cruise 11 (table 14), about half of the fish were tagged and monitored through the cannery. Of the tagged sample, all bigeye tuna were rejected; only 10.9 percent by number, or 11.2 percent by weight of the yellowfin were rejected. While more evidence is required for final conclusions, it appears that rejections are economically prohibitive for bigeye and undesirably high, though not necessarily prohibitive, for yellowfin. The tendency toward dark-colored flesh was greater among the large yellowfin than the smaller ones. With more knowledge of the categories of fish tending toward undesirably dark flesh and the relative distribution of these categories of fish on the fishing grounds it may be possible, by selective fishing, to reduce the proportion of undesirable fish in the catch.

Table 13.--Summary of shark-bitten tuna

Smith cruise	Number of tuna caught	Number of sharks caught	Number of shark-bitten tuna	Percent[1] shark-bitten tuna
5	75	55	20	26.7
7	210	94	60	28.6
11	582	79	83	14.3
Total	867	228	163	18.8

[1] Some of the shark-bitten tuna were not damaged to an extent which would preclude their use commercially.

Table 14.--Summary of rejected tuna, Smith Cruise 11[1].

	Number tagged	Weight of fish	Number rejected[2]	Weight rejected	Percent rejected (by number)	Percent rejected (by weight)
		pounds		pounds		
Bigeye	33	5,362	33	5,362	100	100
Yellowfin	202	22,071	22	2,470	10.9	11.2
Total	235	27,433	55	7,832	23.4	28.5

[1] The table includes only those fish which were tagged and followed through the cannery operations.

[2] Off color--not satisfactory for packing as commercial light-meat tuna.

SUMMARY

1. There were three longline cruises during 1950 and 1951. These were designed to ascertain the distribution and abundance of deep-swimming tunas in the central equatorial Pacific Ocean.

2. The longline catch was composed of large tunas, e.g., 80- to 150-pound yellowfin tuna. Surface catches in the same general area were composed of smaller individuals. This is apparently the result of an ecological preference rather than gear selection.

3. At the longitudes surveyed (150°-160° W. longitude) there was a concentration of deep-swimming yellowfin tuna between 1° - 6° N. latitude. This concentration appears to have been due to an increased food supply resulting from equatorial upwelling of rich water.

4. The oceanic concentration of deep-swimming tunas did not appear related to the islands of the central Pacific.

5. Frequently, catches in the immediate vicinity of small islands were better than their oceanic counterparts, indicating that these islands exert an influence favorable to tuna within a few miles of their shores.

6. The deepest-fishing hooks of the longline gear frequently caught more tuna than hooks fished at a shallower level.

7. Generally males greatly outnumbered females in longline catches of tunas.

8. The equatorial stocks of deep-swimming tunas appear to represent a resource capable of supporting an American fishery.

APPENDIX

The data included in the appendix are not necessary to the main arguments of the paper. They represent valuable field data that are worthy of record.

Table 15.--Average[1] vertical position of isotherms on stations 1 through 7, Smith Cruise 5, in the vicinity of Canton Island. All depths are in feet.

Station	Depth to top of thermocline[2]	Depth of isotherms			Surface temperature (Fahrenheit)[3]
		60°F	70°F	80°F	
1	490	654	585	464	81.2°
2	493	675	592	458	80.9°
3	483	697	563	447	81.2°
4	426	675	588	439	81.9°
5	417	685	598	418	81.4°
6	447	673	608	448	81.3°
7	460	670	581	466	81.1°

1/ Three to six 900-foot bathythermograms were taken at each station.

2/ Top of thermocline is the point of major change of temperature with depth. When the change was not well defined selection was somewhat arbitrary. Generally this occurred near the Equator.

3/ Temperatures taken with bucket thermometer

Table 16.--Average[1] vertical position of isotherms on stations 13 through 22 *Smith* Cruise 11. All depths are in feet.

Station	Depth to top of thermocline	Depth of isotherms			Surface temperature (Fahrenheit)[2]
		60° F	70° F	80° F	
13	252	517	431	344	82.6°
14	287	523	437	383	82.5°
15	264	536	470	366	82.8°
16	400	534	478	410	82.5°
17	484	518	504	266	81.4°
18	214	536	474	297	82.2°
19	372	558	469	399	82.7°
20	286	530	434	344	82.6°
21	232	482	400	270	82.1°
22	202	466	408	238	81.6°

1/ Five 900-foot bathythermograms were taken at each station.

2/ Temperatures taken with bucket thermometer

Table 17.--Wind direction and force[1] on stations during *Smith* cruises 5, 7, and 11

Station	*Smith* Cruise 5		*Smith* Cruise 7		*Smith* Cruise 11	
	Prevailing wind direction	Force of wind (Beaufort scale)	Prevailing wind direction	Force of wind (Beaufort scale)	Prevailing wind direction	Force of wind (Beaufort scale)
1	E	4	-	-	E	5
2	E	4	-	-	NE	4
3	E	4	-	-	E	4
4	E	2	-	-	NE	5
5	S	3	-	-	NE	4
6	E	4	-	-	NE	3
7	E	5	-	-	S	5
8	-	-	-	-	E	2
9	-	-	E	5	NW	3
10	-	-	E	4	SE	5
11	-	-	E	4	SE	4
12	-	-	NE	6	SE	4
13	-	-	SW	4	E	4
14	-	-	E	4	SE	4
15	-	-	SE	4	SE	4
16	-	-	SE	5	SE	4
17	-	-	E	5	SE	5
18	-	-	E	5	SE	4
19	-	-	S	4	SE	3
20	-	-	E	5	E	5
21	-	-	SE	4	SE	4
22	-	-	SE	5	E	4
23	-	-	E	4	SE	4
24	-	-	E	5	SE	4
25	-	-	SE	4	SE	5
26	-	-	E	5	SE	5
27	-	-	E	5	SE	4
28	-	-	E	4	E	4
29	-	-	E	4	-	-
30	-	-	E	5	-	-
31	-	-	SE	4	-	-
32	-	-	E	3	-	-
33	-	-	E	4	-	-
34	-	-	NE	5	-	-
35	-	-	E	4	-	-

1/ Values are averages of several observations taken throughout the day. Beaufort numbers have the following relation to knots - Force 0 (>1), 1(1-3), 2(4-7), 3(8-12), 4(13-18), 5(19-24).

Table 18.--Complete catch records, Smith Cruise 5.

Station	Yellowfin	Albacore	Marlin	Sharks
1	9	-	1	11
2	5	-	-	7
3	12	-	2	16
4	2	2	-	1
5	23	-	1	11
6	-	-	-	6
7	20	2	2	3

Table 19.--Complete catch records, Smith Cruise 7.

Station	Yellow-fin	Big-eye	Skip-jack	Marlin	Dolphin	Sharks	Others
9	-	-	-	-	1	5	2[1]
10	-	-	-	2	2	2	-
11	-	-	-	2	-	4	1[1]
12	-	1	-	1	3	1	1[1]
13	-	-	-	1	-	1	-
14	2	2	1	2	-	3	-
15	5	-	-	-	3	6	1[2]
16	4	-	-	-	-	2	-
17	4	-	-	1	-	2	-
18	-	-	-	2	-	1	-
19	26	-	-	1	-	6	-
20	12	-	-	-	-	3	-
21	7	-	-	-	-	10	2[3]
22	1	-	1	1	-	3	1[4]
23	1	2	1	1	-	4	1[4]
24	6	2	-	-	-	8	2[4]
25	5	4	-	-	-	5	-
26	24	-	-	-	-	2	-
27	10	1	-	2	-	6	-
28	8	-	-	-	-	2	-
29	27	-	-	-	-	-	-
30	19	-	-	2	-	3	-
31	6	1	-	-	-	4	-
32	12	6	-	-	-	1	-
33	4	2	1	-	1	3	-
34	-	-	1	1	1	6	3[1]
35	-	1	-	-	3	1	2[1]

1/ Lancet fish
2/ Wahoo
3/ One lancet fish, one barracuda
4/ Sailfish

Table 20.--Complete catch records, Smith Cruise 11.

Station	Yellow-fin	Big-eye	Skip-jack	Albacore	Marlin	Dolphin	Sharks	Others
1	-	16	-	-	2	-	-	-
2	-	6	-	-	1	2	-	-
3	-	-	-	-	-	-	1	3[1]
4	3	5	-	-	2	1	3	4[2]
5	6	3	-	-	-	-	3	-
6	2	6	-	-	-	2	4	2[3]
7	4	2	-	-	2	1	1	1[4]
8	23	6	-	-	1	-	9	1[4]
9	12	2	-	-	-	-	4	1[4]
10	38	4	-	-	1	-	4	-
11	25	2	1	-	2	-	1	-
12	19	10	1	-	1	-	1	-
13	37	1	3	-	-	-	1	-
14	5	2	2	-	-	-	1	-
15	17	4	2	-	-	-	2	-
16	43	5	2	2	-	-	-	-
17	30	-	-	-	2	-	22	-
18	11	-	3	-	1	-	-	-
19	20	3	1	-	1	-	2	-
20	30	2	3	-	-	-	1	2[4]
21	15	8	-	-	-	-	3	1[4]
22	71	-	1	-	-	-	-	-
23	31	1	-	1	-	-	2	-
24	5	-	-	1	-	-	7	-
25	4	1	-	1	-	-	4	-
26	1	3	1	2	-	1	1	-
27	1	2	3	-	1	1	2	-
28	5	-	-	-	-	-	-	-

1/ Lancet fish

2/ Three lancet fish, 1 wahoo

3/ One lancet fish, one sailfish

4/ Wahoo

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